INTERPACK 99

Failure Engineering Study and Accelerated Stress Test Results for the Mars Global Surveyor Spacecraft's Power Shunt Assemblies

Mark Gibbel, Tim Larson

JPL,

California Institute of Technology

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INTRODUCTION

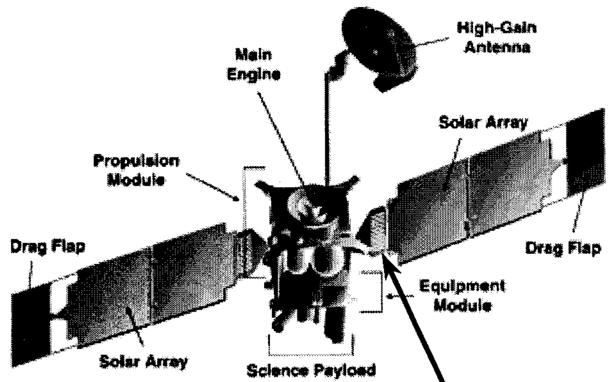
- **USE METHODOLOGY FOR IDENTIFYING DOMINANT FAILURE MECHANISMS**
  - IDENTIFY SPECIFIC FAILURE MECHANISMS IMPACTED BY CHANGE IN MISSION REQUIREMENTS
  - IDENTIFY SPECIFIC TESTS/ANALYSES THAT COULD ASSESS THE RISK ASSOCIATED WITH NEW MISSION REQUIREMENTS
- **DESIGN & PERFORM TESTS**
  - DEFINE FAILURE MODELS FOR TALL POLE FAILURE MECHANISMS IDENTIFIED ABOVE
    - ACCELERATION PARAMETERS & LIMITS OF APPLICABILITY

MGS PSA POST-LAUNCH QUALIFICATION TEST DESIGN BACKGROUND

- POST LAUNCH FAILURE OF AN UNRELATED PART AFFECTS FLIGHT PLAN
- THE PREFERRED NEW PLAN INVOLVES THE ADDITION OF MANY DEEP THERMAL CYCLES TO THE POWER SHUNT ASSEMBLIES **(PSA'S)**
- NEW PLAN EXCEEDS:
  - PREVIOUS ACCEPTANCE COLD LEVEL (BY 45C)
  - FATIGUE LIFE DATA ON PACKAGING DESIGN

MGS S/C

CRUISE CONFIGURATION



Set of 11 Power Shunt Assemblies on each solar array yoke

ENGINEERING PROBLEM & RELATED QUESTIONS

QUESTIONS:

- DOES THE ON-ORBIT HARDWARE HAVE SUFFICIENT LIFE TO SURVIVE THE NEW MISSION PROFILE?
- HOW CAN THIS BE ANSWERED POST LAUNCH?

NEEDS:

- FAST VERIFICATIONS/TEST(S) THAT WILL CONFIRM THE MOST LIKELY FAILURE MECHANISM(S) ***AND*** THEIR LIKELIHOOD OF OCCURRENCE DURING THE NEW MISSION

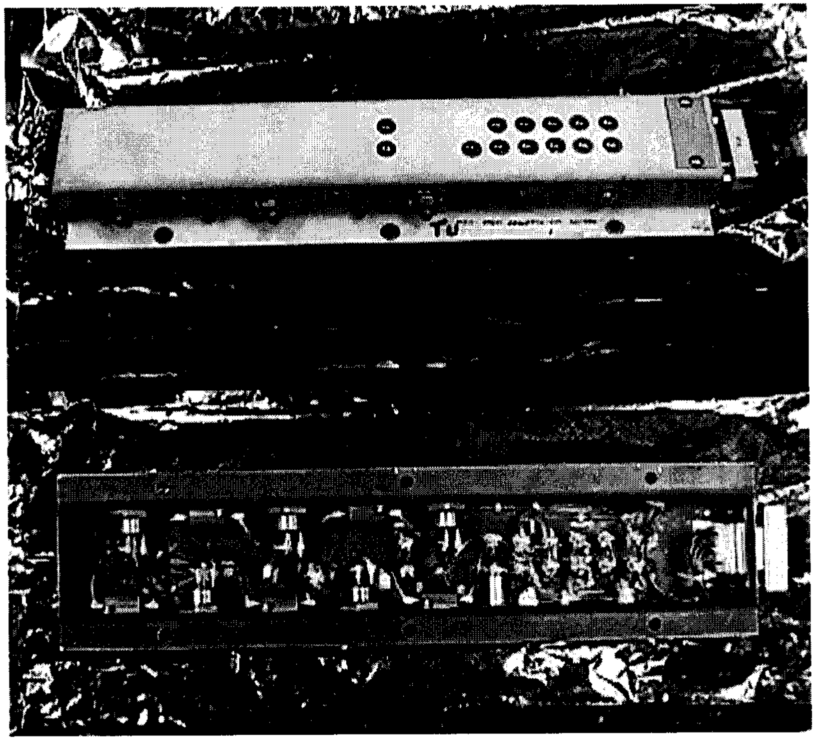
SOLUTION:

- **VARIETY OF ANALYSES, SIMPLIFIED FAILURE MECHANISM MODELS MATERIAL PROPERTY MEASUREMENTS AND** ***HIGHLY ACCELERATED TEST(S)*** THAT WILL VERIFY THE MOST LIKELY FAILURE MECHANISM(S) AND THEIR LIKELIHOOD OF OCCURRENCE DURING THE NEW MISSION

PSA HARDWARE DESIGN

PHYSICAL DESCRIPTION

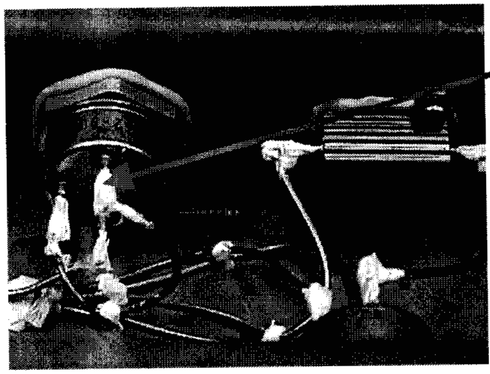
- SHEET METAL HOUSING
- ONE DRIVE Tx,
- FIVE DRIVEN Tx (4 Redundant)
- PLUS ASSOCIATED R's & C's
- ALL PARTS HEAT SUNK DIRECTLY TO METAL HOUSING (I.e. NO CIRCUIT BOARD)



FUNCTIONAL DESCRIPTION

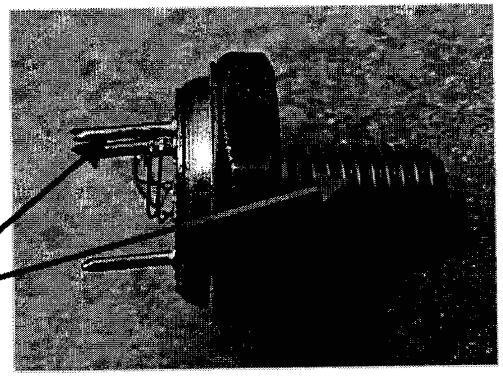
- PROVIDE REGULATION OF SOLAR PANEL POWER BY SHUNTING EXCESS POWER
- 11 PSA's PER SOLAR PANEL

DRIVEN TRANSISTOR PACKAGING DETAIL



Close-up of driven transistor bonded to sheet metal housing. Note all external wire interconnects are coated with a dielectric (white material)

Posts are gold plated over Nickel. Threaded stud is made of copper that has been plated.



Emitter Post, Design uses Dual Emitters and redundant bondwires for each emitter.

Base Post, Single Base with redundant bondwires

Bondwires number 1-6 going counter clockwise starting here for Pull Test Data

Bondwire No. 6.

BeO Header bonded to head of copper stud, with gold metalization on top of header and gold eutectic die bond.

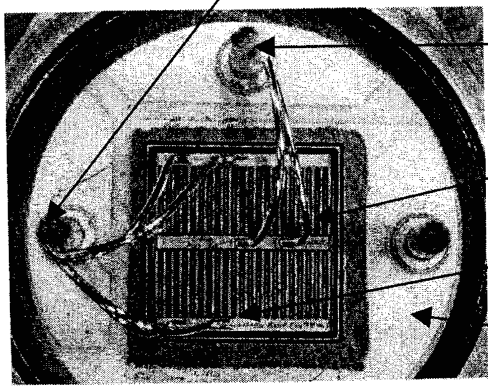


Figure 7. Top view of Transistors showing bondwire configurations. Bondwires are dead soft Aluminum 0.010 inches in Diameter on Aluminum metalization. Posts are Nickle. All are bonds ultrasonic. Bonds to die are orthodyne bonds while bonds to post are wedge bonds.

EXPERIMENT DESIGN

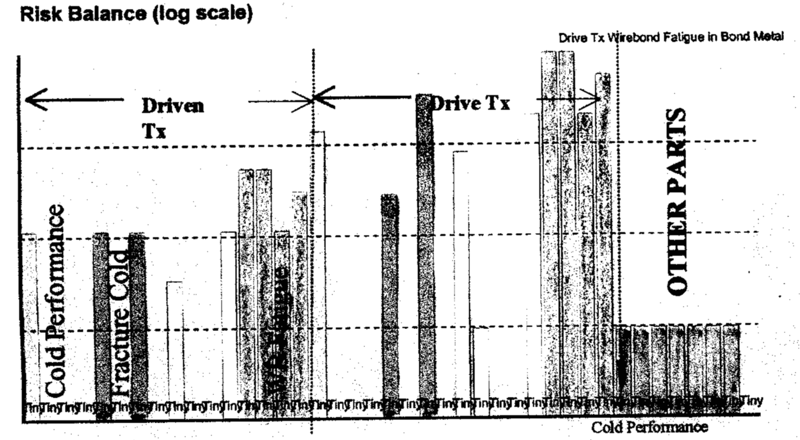
- DRIVEN BY PROCESS THAT IDENTIFIES THE DOMINANT FM'S DUE TO CHANGED REQUIREMENTS (USING JPL/DDP TOOL)
- USE SPARE FLIGHT HARDWARE
- BROAD SPECTRUM OF FAILURE MECHANISMS ACCELERATED DURING TEST
- TEST LIMITS SET BY A COMBINATION OF ANALYSIS AND A STEP STRESS TEST ON THE ENGINEERING MODEL UNIT
- DEGRADATION FROM TEST ESTABLISHED BY PERFORMING BONDWIRE PULL TESTING AFTER LIFE TEST COMPLETION

FM IDENTIFICATION/EVALUATION PROCESS

- **USE DEFECT DETECTION & PREVENTION (DDP) TOOL**
  - IDENTIFY SPECIFIC FAILURE MECHANISMS THAT CAN IMPACT THE NEW MISSION REQUIREMENTS
    - (MATRIX OF REQUIREMENTS VS. FAILURE MECHANISMS THAT CAN IMPACT THESE REQUIREMENTS)
  - IDENTIFY SPECIFIC TESTS/ANALYSES THAT COULD ASSESS THE RISK ASSOCIATED WITH IDENTIFIED FM'S
    - (MATRIX OF PREVENTIONS AND/OR DETECTION ACTIVITIES VS. FAILURE MECHANISMS THAT CAN BE PERFORMED)
  - YIELDS RESIDUAL RISK (BY SPECIFIC FAILURE MECHANISMS)

Residual Risk = How much I care x How much I missed it

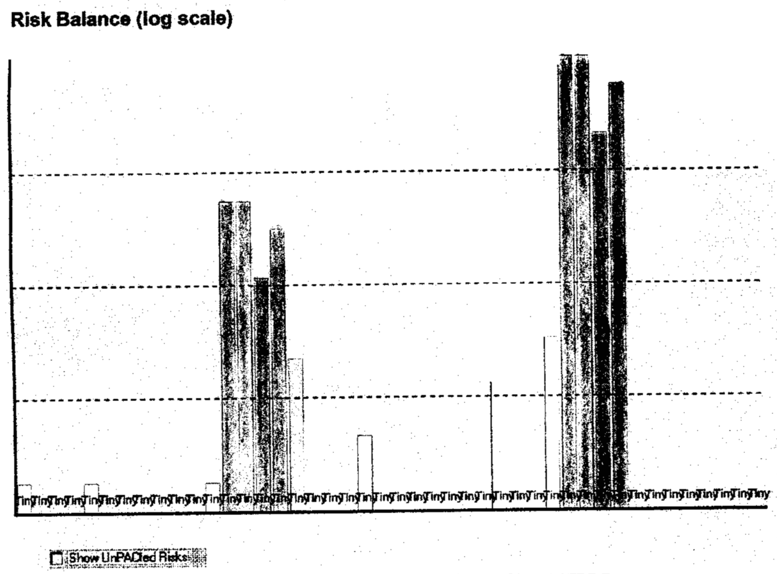
RESIDUAL RISK VS. PACT'S PERFORMED



PACTs

Selected Estimate Fatigue Life to be Consumed i Mission

- ☑ Survive Launch and Flight to date
- ☑ Perform Life Test on Shunt Assy's
  - ☑ Test the Fracture Toughness of BEO Header
  - ☐ Measure the CTE of BEO (-150C to +100C)
  - ☐ Perform Post Life Test Bondwire Pull Test
  - ☐ Exposure Unit to New Cold Level With Margin



BLUE= COLD PERFORMANCE, GREEN = FRACTURE DUE TO COLD, WHITE = MATERIAL FAILURE DUE TO SHEAR, TENSION OR COMPRESSION, RED = WIREBONE FATIGUE FAILURE, ORANGE = OTHER PART FAILURE

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EXPERIMENT DESIGN DETAILS

- **DDP KEY RESULTS/DRIVING FAILURE MECHANISM**
  - BONDWIRE FATIGUE (PARTICULARLY IN THE DRIVE Tx)
  - BeO DISK (HEADER) FRACTURE NEEDS TO BE VERIFIED
  - PACKAGING STRESS (BONDLINE SHEAR, DIE FRACTURE, ETC.)
  - SYSTEM PERFORMANCE @ COLD

- **FAILURE MECHANISMS EXERCISED BY TEST**
  - UNIT PERFORMANCE VS. TEMPERATURE,
  - WIREBOND FATIGUE LIFE,
  - PACKAGE STRESSES
  - POWER RELATED FAILURE MECHANISMS

- **FAILURE MECHANISMS ACCELERATED IN TEST**
  - WIREBOND FATIGUE LIFE,
    - CTE EFFECTS INTEGRATED OVER THE TEMPERATURE RANGE
  - PACKAGE STRAINS/STRESS ASSOCIATED WITH MATERIAL PROPERTY CHANGES OVER THE TEMPERATURE RANGE

EXPERIMENT DESIGN DETAILS

- **TEST ARTICLES**
  - TWO PSA FLIGHT SPARE UNITS & ONE ENGINEERING MODEL PSA
  - THREE FLIGHT SPARE DRIVEN Tx's (FROM THE SAME LOT DATE CODE)
  - CONTROL DRIVE AND DRIVEN Tx's USED (I.E. NOT LIFE TESTED)

- **TEST LIMITS ESTABLISHED**
  - STEP STRESS TEST ON THE ENGINEERING MODEL UNIT (-145C REACHED LIMIT OF CHAMBER +125C)

- **DAMAGE ACCUMULATION VERIFICATION**
  - DEGRADATION FROM TEST ESTABLISHED BY PERFORMING BONDWIRE PULL AFTER THERMAL CYCLING
- **TEST CONDITIONS**
  - PSA'S POWERED "ON"
  - SPARE TRANSISTORS NOT POWERED
  - 2,000 CYCLES FROM -125C TO +100 SELECTED
  - RAMP RATE ON THE ORDER OF 60C/MINUTE

ACCELERATION FACTORS FOR PURE AL. WIREBOND FATIGUE

Mission Phase	Cycles	TEMPERATURE RANGE			Strain	Range of PARIS POWER LAW EXPONENT for Alumimun		Equivelent Test Cycles (-125C TO 100C)	
		T1	T2	dT		(Test/Env.) @ 1.5	(Test/Env.) @ 1.7	1.5	1.7
Acceptance Test	18	90	-60	150	0.0029	2.1	2.3	8.6	7.7
T/V from	16	60	-55	115	0.0022	3.1	3.7	5.1	4.4
Cruise	4700	47		*47*	0.0009	12.0	16.7	**391.7**	281.3
Pre-Eclipse ANS Cycling (every 100 min from 9/11 to 1/2)	1627	10	-10	20	0.0004	43.2	71.4	37.6	22.8
Pre-Eclipse AB Drag Pass (P-0 to P-90)	90	10	-50	60	0.0012	8.3	11.0	10.8	8.2
Phase 1 Eclipse Season ANS Cycling (Every 100 Min from 1/2 to 4/1	1280	10	-10	20	0.0004	43.2	71.4	29.6	17.9
Phase 1 Eclipse Season Eclipse & AB Drag Pass (1/2 to 4/1)(60 min eclipse)(P-90 to P-300)	210	10	-80	90	0.0015	5.9	7.5	35.7	28.2
Additional Eclipse Season	500			100	0.0019	3.9	4.6	**129.3**	108.0
Science ANS Cycling (4/1 to 11/1/98)(100 min spin)	3080	10	-10	20	0.0004	43.2	71.4	71.3	43.1
SCI(4/1 to 11/1/98)(6 hr orbit)(60 min Offf-Point)	856	10	-70	80	0.0015	5.4	6.8	158.4	126.5
Eclipses during Science (4/1 to 11/1/98)(Avg 30 min)	856	10	-50	60	0.0012	8.3	11.0	102.9	77.6
Phase 2 ANS Cycling (11/1 to 4/1/99)(100 min spin)	2174	10	-10	20	0.0004	43.2	71.4	50.3	30.4
Phase 2 AB/Eclipse (11/1 to 4/1/99)(P-301 to P-900)	600	10	-70	80	0.0015	5.4	6.8	111.1	88.7
Mapping 1 Mars yr =687 days 40 Min Eclipses 12 orbits per day	8760	10	-50	60	0.0012	8.3	11.0	**1,053.1**	794.0
Relay phase 3 Earth years	0	10	-50	60	0.0012	8.3	11.0	0.0	0.0
Totals	24,767							**2,196**	**1,639**

LIFE TEST RESULTS

2000 CYCLES (-125C to 100C)

	Pull Strength (grams)						Location of Failure Site (blank= failure in bond at die)						Thernal Cycle	Power Cycle	Control Sample	Type of Device	Notes
S/N	1	2	3	4	5	6	1	2	3	4	5	6					
71	216	371	360	337	511	425			Die Heel	Die Heel	Midspan	Die Heel			x	Driven	
81	410	386	397	419	489	386			Die heel	Die Heel	Midspan	Die Heel			x	Driven	
119	273	263	416	460	439	456			Die Heel	Die Heel	Midspan	Die Heel			x	Driven	1
80	18	21	318	200	0	NR							x			Driven	
91	16	62	58	175	93	86							x			Driven	1
155	50	67	175	167	310	67							x			Driven	
83	19	16	210	227	53	40							x	x		Driven	
94	15	15	155	86	59	219							x	x		Driven	
121	91	165	153 *	158	23	NR			Post Heel				x	x		Driven	
143	78	207	282	289	145	331							x	x		Driven	
151	38	33	24	186	0	19							x	x		Driven	
191	31	52	171	208	24	100							x	x		Driven	1
193	33	81	65	113	19	81							x	x		Driven	
194	73	57	107	153	137	105							x	x		Driven	
1	410	411	–	–	–	–	Die Heel	Die Heel	–	–	–	–			x	Drive	2
2	507	402	–	–	–	–	Die Heel	Die Heel	–	–	–	–			x	Drive	2
167	165	189	–	–	–	–			–	–	–	–	x	x		Drive	

Notes: NR = not recorded

1) Original FA performed at LM wiring convention not detailed beyond emitter side side and base.

2) These devices were from current manufacturer's lot due to lack of spares of original flight parts.

3) Failure classification according to Mil STD 883c, Notice 4, Paragraph 3.2.1a: Table entries transulate to: Failure in bond = a-3; Die Heel = a-1; Midspan = a-2

Table 3. Summary of failure analysis results (pull strengths and failure location).

DETAIL VIEW OF A DRIVEN TRANSISTOR

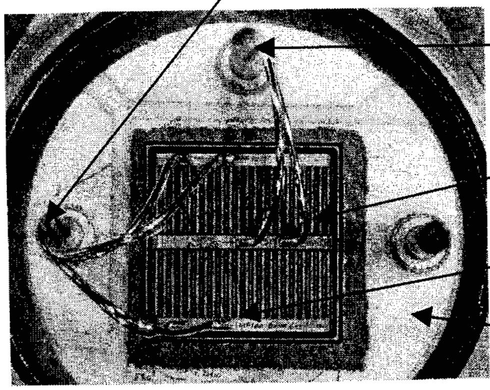
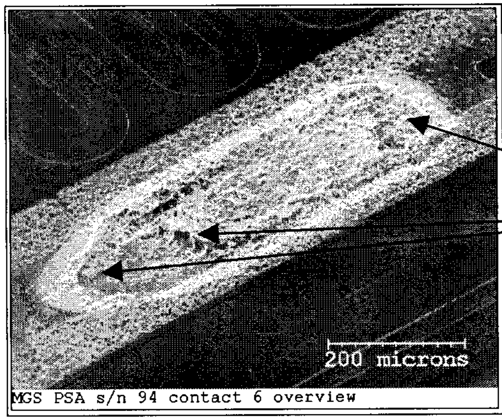


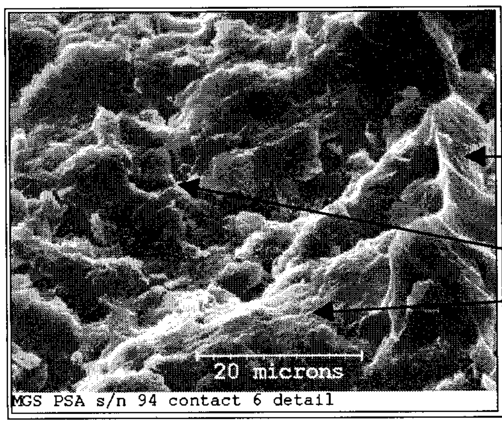
Figure 7. Top view of Transistors showing bondwire configurations. Bondwires are dead soft Aluminum 0.010 inches in Diameter on Aluminum metalization. Posts are Nickle. All are bonds ultrasonic. Bonds to die are orthodyne bonds while bonds to post are wedge bonds.

CLOSE UP OF A TYPICAL FAILURE SITE



Major bonding areas. Minor bonding appears to have also occurred around the perimeter. Light colored band was most likely caused by the ultrasonic scrubbing action outside the bond area. (The heel of the bond is at the XXX of the photo).

Figure 8. View of bond pad #6 in S/N 094 showing area where bonding occurred.



"Taffy" structures on shown here indicate a ductile failure do to pull testing.

The striations shown in these regions are indicative of damage created by fatigue.

Figure 9. Close up of region shown by middle arrow in Figure XXX.

TEST ACCELERATION FACTORS FOR AL. ON AL.WIREBONDS

- MISSION INVOLVES MANY CYCLES ~25,000
- TABLE INTEGRATES CTE EFFECTS OVER TEMP RANGE:
  - CTE NOT CONSTANT OVER TEMPERATURE
  - MISSION EVENTS EQUATED TO NUMBER OF TEST CYCLES
  - TOTAL MISSION EQUAL TO ABOUT **1,600 TO 2,200** CYCLES FROM -125 TO +100C
- RANGE FROM ABOUT:
  - **5 X TO 70 X**

WIREBOND PULL TEST RESULTS

- **TABLE SHOWS**
  - BREAKING STRENGTH FOR 90 WIREBONDS
  - WIREBOND FAILURE SITE
  - TEST CONDITIONS/Tx TYPE

PULL STRENGTHS:

- **VIRGIN WIREBONDS**
  - TRADITIONALLY VARY GREATLY
  - HERE VARIATION RELATIVELY SMALL (MOST CASES $\pm$10%)
  - MIL SPEC 883 SAYS OVER 80 g (BOL) IS ACCEPTABLE
- **STRESSED WIREBONDS**
  - ALL SIGNIFICANTLY DEGRADED
  - TWO HAD NO PULL STRENGTH
  - MANY LESS THAN 20% LIFE REMAINING (LAST 20 % GOES VERY FAST)

FAILURE SITES & TEST STRESSES

- VIRGIN WIREBONDS FAILED MOSTLY IN THE **HEEL** ON THE DIE SIDE
- STRESSED WIREBONDS MOSTLY **FAILED IN THE BOND METAL** ON THE DIE SIDE
- FAILURE RESULTS ABOUT **SAME** FOR POWER +THERMALLY VS. JUST THERMAL CYCLED
  - SMALL % OF CAPABILITY USED

CONCLUSIONS

- **DDP TOOL**
  - EFFECTIVE METHODOLOGY FOR IDENTIFYING SPECIFIC FAILURE MECHANISMS TO DESIGN THE TEST AROUND
- **TEST DESIGN PROCESS**
  - SIMPLIFIED MODELS AVAILABLE IN THE LITERATURE & MATERIALS PROPERTY DATA
  - INCLUDED A VERIFICATION OF THE MOST LIKELY FAILURE MECHANISMS
- **TEST RESULTS SHOWED**
  - THAT THE FM'S THE WAS TEST DESIGNED AROUND WERE THE MOST LIKELY TO OCCUR
  - THE DESIGN "AS IS" CAN BE EXPECTED TO HAVE SUFFICIENT LIFE FOR PREFERRED NEW MISSION PLAN
  - MIL STANDARDS NOT NECESSARILY APPLICABLE FOR THERMAL CYCLING ENVIRONMENT